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Field Report

Physical and environmental hazards in the prosthetics and orthotics workshop: a pilot study

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Abstract: Prosthetists and Orthotists (P&O) are exposed to physical hazards within the workshop environment. Concern regarding these exposures has been expressed by P&Os; however, little research has been undertaken. Exposures to noise and volatile organic compounds in amounts larger than statutorily allowed can have adverse short and long term consequences on people's health. To identify and quantify hazardous noise and chemical exposures in a typical P&O workplace. Noise and volatile organic compound testing was undertaken in 2011 and 2013. Modifications to the workshop occurred between these testing times and the impact of these changes examined. The levels of volatile organic compounds was very low in all areas in 2011 and 2013. Noise levels were high and staff require the use of PPE to prevent exposure beyond levels prescribed in the Australian Standards. Conclusions. Occupational environmental exposures in P&O are of concern to the profession. A pilot study of one facility demonstrated that Occupational Noise exposures are high and may result in hearing loss and other adverse health outcomes. Occupational chemical exposures through volatile organic compound exposures are relatively low. Further, systematic investigation is required to develop evidence-based control strategies.

Key words: Work environments, Noise, Volatile organic compounds, Exposure, Health care

Background

Work environments expose workers to a range of physical and psychosocial hazards linked to risks of injury and disease[1]. The combination of the work undertaken, the work system design and the work environment determines the hazardous exposures. Common workplace physical hazards include occupational environmental exposures (OEE) such as noise, vibration, thermal comfort, lighting/radiation and chemical exposures[2], with health impacts including the development of hearing loss, cancers, dermatitis and asthma[3].

Occupational Health and Safety legislation provides clearly regulated occupational exposure limits identifying what exposure is deemed to be hazardous to health, and thus not acceptable in the workplace. For the purpose of this study, OEE are defined as exposures related to physical hazards. Little research into OEE has been undertaken in Prosthetics and Orthotics (P&O) work although noise and chemical exposures have been identified as stressors in the workplace for Prosthetists and Orthotists (P&Os)[4, 5].

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Occupational environmental exposures in prosthetic and orthotics

Environmental context and injury claims. In P&O OEE occur in the non-clinical workshop setting, which is unlike any other health care work environment, resulting in exposures unique to this group of allied health workers. This 'industrial' environmental setting suggests it is more appropriate to compare risks in the P&O work environment with that of other manufacturing work environments, rather than to traditional clinical workplaces.

From 2000–2014, Australian P&O workers recorded a total of 1,350 compensation claims for injuries resulting in 1 wk or more of lost work time[6)]. In 2011, the total P&O Australian workforce was 404[7)], and 105 (or 26% of P&Os) compensation claims were accepted[6)].

Worker context. P&Os have reported concerns about risks to their health in relation to workshop noise and other occupational physical exposures "The thing that I worry about most is the atmospheric OH&S risk that we suffer from. So, be that constant noise or fumes or dust…" (p6)[4)]. OEE physical hazards impact workers' personal states through three different routes; absorption, (via skin contact), inhalation, (breathing airborne contaminants) and ingestion, (hand to mouth contact)[8)]. In P&O, common OEE include noise, chemical and airborne particles. These exposures arise from the use of a range of workshop tools and chemicals for example pneumatic chisels, contact adhesives, acetone, and laminating devices.

Occupational environmental exposures—noise

Noise induced hearing loss (NIHL) is caused by excessive exposure to high levels of noise[9)]. The long-latency and chronic nature of NIHL and underreporting makes it difficult to accurately attribute claims numbers or costs to these hazardous exposures[8, 10)]. Despite this, NIHL is a major workplace compensable industrial disease and a significant economic problem in Australia and other developed countries[11, 12)].

Jurisdictional regulations including the Safe Work Australia Model Work Health and Safety Regulations[13)], and the Victorian, Occupational Health and Safety Regulations[14)], set acceptable noise exposures at 85 dB(A)'averaged' over 8 h, with a peak sound limit, of 140 dB(A). For example, a pneumatic chisel is equivalent to approximately 115–120 dB(A) in comparison to an iPods maximum volume at 105 dB(A), and a gunshot at 140 dB(A)[8, 15)]. Exposure to occupational noise can reduce hearing acuity, cause tinnitus[16)] and is also associated with increased heart rate and hypertension, risk of cardiovascular disease and a number of psychosocial factors[17)].

Occupational environmental exposures—chemicals

Chemical exposure is of concern for P&Os[4)]. Chemical OEE for P&Os include many hazardous substances such as fiberglass, styrene, acetone, toluene and Plaster of Paris. Inhaling styrene may be linked to a number of potential negative health effects including eye, noise and throat irritation, nervous system affects[5)] and development of cancers (Agency for Toxic Substances and Disease Registry 1995). Acetone (an organic solvent) is potentially toxic on ingestion, moderately irritating to the eyes and has been associated with fetal abnormalities following maternal in utero exposure[18)]. Plaster dust has been identified as a skin and airborne irritant[19)].

OEE in P&O has not been well researched despite reported concerns within the profession[4, 5)]. Identification of OEE in P&O facilities and quantification of the hazards experienced is needed to improve understanding of exposures of P&Os to noise and chemicals in their workplace.

Aim

The aim of this study is to identify and quantify hazardous noise and chemical exposures in a typical P&O workplace to inform the development of best practice recommendations for improvement.

Method

An occupational hygienist was contracted to identify and assess noise and chemical exposures in a large hospital-based Victorian P&O workshop facility. Assessments were undertaken in April 2011, and subsequently in April 2013 following interventions designed to improve noise levels related to extraction ventilation systems.

The Prosthetics Department in the current study consists of an open workshop area surrounded by a gluing bench and plaster area, with adjacent separate Machine (3) and Lamination rooms (4) (Fig. 1). Three air supply registers are located in the ceiling of the general workshop and provide conditioned air flow to the area. Walls between the workshop and adjacent office and clinical rooms are non-insulated ply board.

Gluing bench (1): used to manually apply contact glue (Toluene-free) to materials used for prosthetics and orthotics. A twin slot-type exhaust ventilation system is located at the rear, designed to capture evaporating glue fumes with a moveable extraction hood located which can be

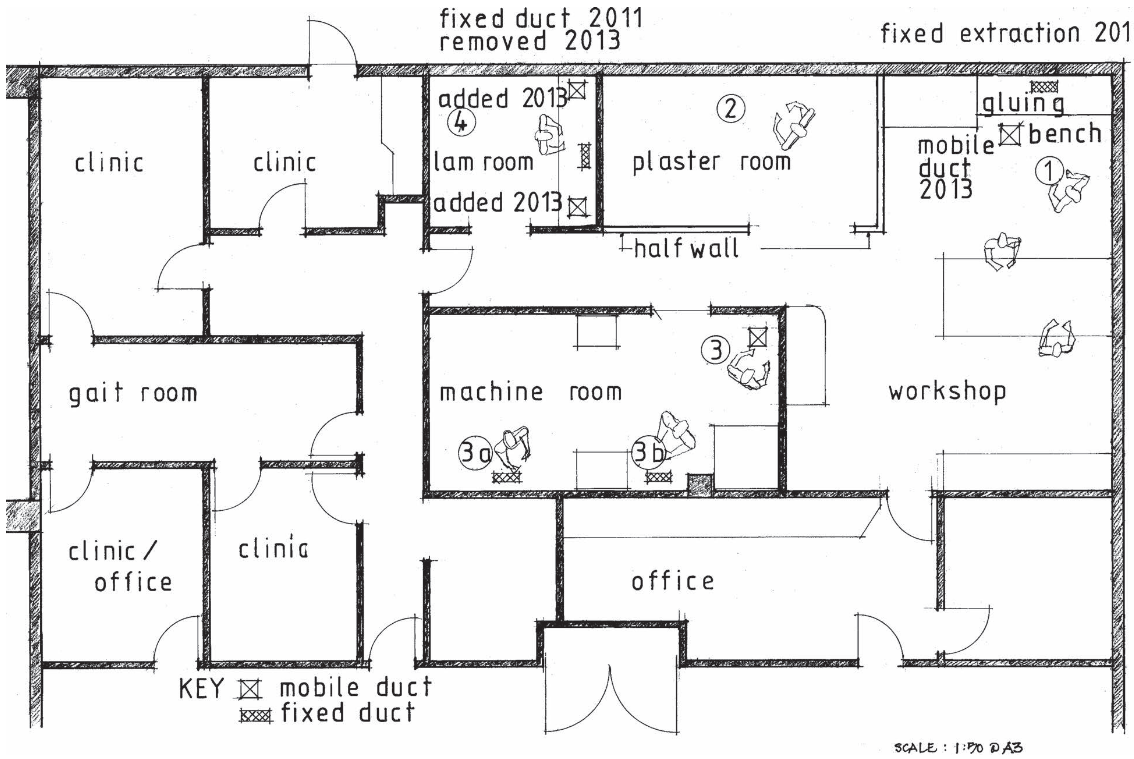

Fig. 1. Workshop layout.

moved over the material pieces after gluing or moulding.

Plaster area (2): located in one corner of the general workshop, Plaster of Paris is handled to manufacture positive casts and make modifications. This area is separated from the general workshop by half-height partitions on two sides.

Machine room (3): located off the general workshop and contains linishing/grinding machines used for manufacturing of orthoses and prostheses, with one air supply vent. Machines have local exhaust ventilation to control airborne dust generation during operation.

Lamination Room (4): located adjacent to the workshop with a bench along one side used for mixing laminating resins. A sliding door separates it from the passageway leading to the general workroom with one small ceiling air supply vent by the room entrance. Various resins, promoters, solvents, glues and pigments are stored in two chemical storage cabinets under the bench, separated such that resins and reactive foams are stored independently of catalysts. Local exhaust ventilation is provided above the mixing bench and through vents in the room, as well as by two moveable extraction hoods which can be positioned over work to ensure fume capture.

Personal protective equipment (PPE)

Staff are provided with full face-piece respirators fitted with ABEK2P3 cartridges which are replaced every 3 months. All staff wear respirators when performing any tasks in the machine room or lamination room, using resins, solvents, glues and when undertaking grinding. Staff are also provided with Class 5 hearing protective devices (ear muffs) PELTOR H10 H/BAND CL5 H10A which must be worn when working in the machine room. Staff also wear steel cap or composite cap safety footwear in all workshop locations.

Assessment of noise

The noise assessment was undertaken with a Larson Davis LxT Type 1 Integrating Sound Level Meter and Breul & Kjaer Calibrator, Type 4230 SNo 419201. The Noise Level Meter was set at a one-min integration interval, a slow time constant and 3 dB exchange rate. The equipment was checked for normal operation and calibration before and after measurements. All measurements were taken in accordance with the relevant provisions in:

(ii) Australian Standard AS/NZS 1269.1:2005 "Occupational Noise Management, Pt 1 Measurement and assessment of noise emission and exposure"[20].

(iii) Australian Standard AS/NZS 1269.3: 2005 "Occu-

Table 1. Acceptable exposure limits for the assessed VOCs[23]

Contaminant	TWA Exposure Standards
Isopropyl Alcohol	400 ppm
Acetone	500 ppm
Ethyly Alcohol	1,000 ppm
Toluene	50 ppm
Xylenes	80 ppm
MEK	150 ppm
Methyl Methacrylate	50 ppm
Pentanes	600 ppm

pational Noise Management, Pt 3 Hearing Protector Program"[21]

Following measurement, results were compared with the noise limits specified in the Victorian Occupational Health and Safety Regulations 2007[22].

Assessment of volatile organic compounds (VOCs)

In Australia, acceptable exposure standards for atmospheric contaminants in the occupational environment are set by Safe Work Australia (formerly the National Occupational Health and Safety Commission). An exposure standard represents an airborne concentration of a particular substance in the worker's breathing zone, exposure to which, according to current knowledge, should not cause adverse health effects nor cause undue discomfort to nearly all workers. The time-weighted average (TWA) exposure standard is based on personnel working a standard 8-h d, 5 d wk (Table 1)[23].

Sampling for volatile organic compounds was taken in the breathing zone of P&O Department staff using SKC 575-002 organic vapour badges worn on the lapel over the course of a standard work day (selected by the assessor for his convenience) and while conducting normal duties.

The organic vapour badges were analysed by TestSafe Australia (Workcover NSW chemical laboratory) using gas chromatography/mass spectrometry. The effectiveness of the local exhaust ventilation systems was assessed by smoke tests and average capture velocity (m/s) readings from air current tubes and anaemometers at the Gluing Bench Slot Ventilation (1) and the extraction hoods (3a) in the workroom and Laminating Room.

April 2011. Monitoring of exposure to volatile organic compounds was undertaken on four staff members during regular department operation. Testing was conducted under normal workshop conditions with employees carrying out their usual duties. Additionally, spot noise measurements were carried out in specific locations (see Fig. 1. locations 2, 3 & 4) around the workshops to assess potential noise emissions from various pieces of equipment.

Interventions

Following the initial assessments in 2011, a series of interventions were implemented to address identified noise issues, including (Fig. 1):

– An upgrade to the extraction unit external to the department.
– Provision of local exhaust ventilation over the mixing bench in the Laminating Room
– The addition of an extraction wall vent in the lamination room and a vent installed in the sliding door endurance to improve the extraction. (4)
– Removal of the walk-in hood and the capture hoods replaced with flexible arm extraction systems to allow s optimum extraction position during lamination.
– The addition of a mobile duct over the gluing bench (3a)

In 2013 testing was repeated, the consultant, methodology, equipment and instruments were all replicated identically with that used in 2011.

Results

The initial assessment was designed to quantify exposures by staff to noise and chemical (VOCs) whilst undertaking normal tasks within the department; the subsequent assessment was to measure exposure levels following the implementation of changes to ventilation systems. The activities undertaken during both assessments were all standard activities with no extra tasks included for the purpose of the assessment. The OEE were measured to identify the ambient exposures in the work areas rather than individual exposures for any particular staff member.

Noise

a) 2011 assessment

Table 2, identifies the 2011 noise levels in specified locations, and the estimated safe exposure times. Ambient noise levels were generally high, and exceeded acceptable levels after relatively short periods in all work areas where equipment was being used. The noise emission was from the work activity point and the air extraction units. The noise from the extraction unit in the lamination room caused noise levels for this room to exceed 85dB(A) and ranged from 89dB(A) to 96dB(A) under different dampener conditions (Table 2).

Table 2. 2011 Noise levels

Area/Operation	LAeq 1 min dB(A)	period before eight h standard exceeded* (hrs:min)	Points where/when measurements taken
Grinding room (3)			
Grinder	88	4:00	During grinding of orthotic.
Grinder	84	10:00	Whilst no grinding was being undertaken but extraction was on.
Grinder	88	4:00	Grinding orthotic
Laminating Room (4)			
Right hand extraction hood	93	1:16	30 cm from hood. Both left and right hood slide gate dampers open.
Right hand extraction hood	89	3:12	30 cm from hood. Both left side gate damper closed and right slide damper open.
Left hand extraction hood	93	1:16	30 cm from hood. Both left and right hood slide gate dampers open
Left hand extraction hood	96	0:38	30 cm from hood. Both left side gate damper closed and right slide damper open

*without hearing protection

Table 3. 2013 Noise levels

Area/Operation	LAeq 1 min dB(A)	period before eight h standard exceeded* (hrs:min)	Points where/when measurements taken
Grinding Room (3)			
Grinder	95	0:47	Fan speed 100% with all other outlets blocked off
Grinder	92	1:35	Fan speed 100% with one other outlet open
Grinder	89	3:11	Fan speed 100% with all other outlet open
Grinder	83	>12	Fan speed 60% and all other outlets closed
Chipping plaster leg mould with air chisel to recover mandrel	103	0:07	At staff member's ear
Chipping plaster leg mould with air chisel to recover mandrel	82	>12	Outside Grinding Room during chisel use.
Laminating Room (4)			
Laminating Room	74	>12	
Gluing Bench (1)			
Gluing Bench	78	>12	Rear extraction only on.
Gluing Bench	75	>12	Both rear extraction and flexible arm extraction on.

*without hearing protection

b) 2013 assessment

Results in Table 3 represent the noise frequencies measured in 2013 following modifications to the workshop and clinic environments.

Modifications to the workshop environment to address reported noise and volatile chemical exposure concerns by staff resulted in reducing noise levels from a maximum peak noise of 96 dB(A) to 74 dB(A). However, changes to improve the extraction system resulted in an increase from 88 to 95 dB(A) during grinder use in the machine room. A reduction in noise levels in the lamination room from 96 dB(A) to 78 dB(A) was recorded following modifications to the ducting setup between 2011 and 2013.

In 2013, specific additional testing was undertaken of the activity 'chipping out a mandrel' following staff reports of excessive noise during this task. Noise levels were recorded as 107 dB(A); the time exposure limit for staff without PPE at this level is calculated at a maximum of 7 seconds per day.

Chemical exposures

Chemical exposures on the day of monitoring for both assessments were within the time weighted average exposures maximum acceptable levels (ppm) as specified by Safe Work Australia for substances outlined in Tables 4 and 5.

Discussion

Noise OEE and VOC were assessed as part of the manufacturing processes of Prosthetists and Orthotists job role. Despite concerns expressed by P&Os regarding VOCs, noise OEE was found to be hazardous whilst VOCs were assessed as well within the regulated acceptable limits. As

Table 4. 2011 Volatile Organic Compounds assessment results

Operator	Process	Total time worn/min exposed	TWA (ppm)	TWA Exposure Standards (maximum allowed)
P&O technician	• Sealing orthotic casts using methylated spirit	474	Methyl Methacrylate = ND	50 ppm
	• Using 3M Super 77 Spray Adhesive		Ethyl Alcohol = 0.37 ppm	1,000 ppm
	• Mixing and applying Eco-Lam Resin and sealing resin		Toluene = ND	50 ppm
	• Grinding and gluing using Foss Adhesive		Xylenes = ND	80 ppm
			MEK = ND	150 ppm
			Acetone = ND	500 ppm
Orthotist	• Plaster Work	471	Methyl Methacrylate = ND	50 ppm
	• Gluing orthoses using toluene-based glue		Ethyl Alcohol = 0.54 ppm	1,000 ppm
	• Grinding Orthoses		Toluene = ND	50 ppm
	• Patient clinics		Xylenes = ND	80 ppm
	• Office work		MEK = ND	150 ppm
			Acetone = ND	500 ppm
Prosthetist	• Cleaning using Foss Solvent	493	Methyl Methacrylate = ND	50 ppm
	• Cast modification using builder's oxide, shellac		Ethyl Alcohol = 1.85 ppm	1,000 ppm
	• Gluing orthoses using Foss Adhesive and solvent		Toluene = ND	50 ppm
	• Patient Review		Xylenes = ND	80 ppm
			MEK = ND	150 ppm
			Acetone = ND	500 ppm
Orthotist	• Making toe prop using Orthoform 2-part silicone	473	Methyl Methacrylate = ND	50 ppm
	• Gluing shoe raise using 12D Adhesive		Ethyl Alcohol = 0.54 ppm	1,000 ppm
			Toluene = ND	50 ppm
			Xylenes = ND	80 ppm
			MEK = ND	150 ppm
			Acetone = ND	500 ppm

ND = Not Detected
No other specific VOC's were detected in any of the samples

Table 5. 2013 Volatile Organic Compound results

Operator	Process	Total time worn/min exposed	TWA (ppm)	TWA Exposure Standards (maximum allowed)
Technician	Sealing orthotic casts using methylated spirits	277	Pentanes = 16.25 ppm	600 ppm
	Using 3M Super 77 Spray Adhesive		Methyl Methacrylate = ND	50 ppm
	Mixing and applying Eco-Lam Resin and sealing resin		Isopropyl Alcohol = 3.94 ppm	400 ppm
			Toluene = ND (50 ppm)	50 ppm
			Xylenes = ND (80 ppm)	80 ppm
			MEK = ND (150 ppm)	150 ppm
			Acetone = 0.58 (500 ppm)	500 ppm
Prosthetist	Plaster Work	387	Methyl Methacrylate = ND	50 ppm
	Office work		Ethyl Alcohol = 4.35 ppm	1,000 ppm
	No gluing but working adjacent to gluing bench		Toluene = ND	50 ppm
			Xylenes = ND	80 ppm
			MEK = ND	150 ppm
			Acetone = ND	500 ppm
Prosthetist	Plaster Work	396	Methyl Methacrylate = ND	50 ppm
	Office work		Ethyl Alcohol = 3.38 ppm	1,000 ppm
	Gluing orthotic using Foss Adhesive and solvent		Toluene = ND	50 ppm
			Xylenes = ND	80 ppm
			MEK = ND	150 ppm
			Acetone = ND	500 ppm

ND = Not Detected
No other specific VOC's were detected in any of the samples

such, staff in this facility are at negligible risk from inhalation to all chemicals measured when working under the conditions at the time of assessment – considered to be normal conditions for this workshop.

The extraction system within the department was upgraded in 2012 and the existing ducting was modified to allow for new mobile ducts to be included to better capture any potential VOCs that may have been present. Modifications to the extraction had little effect on the levels of VOCs recorded; however, they had a detrimental effect on noise levels in the main areas of the department.

A key concern, identified from these assessments, is the cumulative exposure to noise for unprotected individuals throughout the workshop, clinical and office environments. A systematic approach to hazard and risk identification should have found that this was a potential factor requiring development of suitable controls. The number of people in the workshop and using tools and machinery will impact noise levels. Staff absences on the day of testing in 2013, may have resulted in an underestimation of noise levels which should be considered.

Somewhat surprisingly, VOCs results were low with negligible risk identified for harmful levels of chemical exposure. These results, whilst positive for P&Os in the department, must be considered in the particular context. This department has been proactive in substituting high risk materials, with lower risk alternatives, for example styrene and methyl methacrylate free resins, and has invested significant effort in improving their extraction systems, to the detriment of noise levels at times. It should also be noted that for this pilot study it was not practical to assess the levels of non-volatile compounds such as plaster dust and EVA particles. Further assessment of these factors may improve confidence of P&Os and departmental occupational health and safety compliance. The data collection and testing processes carried out were part of one P&O facility's attempt to proactively improve their working conditions. Utilising a systematic risk management approach, may have led to more comprehensive and conclusive outcomes.

As a result of the very low recorded levels of VOC, PPE is actually not required by staff in this workshop when dealing with chemical and organic compounds, but they are used as a sensible precautionary strategy. PPE has low efficacy as a risk reduction strategy, compliance is often poor and elimination or substitution of the hazardous source, engineering changes, are preferred options[8]. This hierarchy of risk controls should be used to guide the development of effective controls. Also, protection through the use of PPE will only be effective for those in the workshop and not those in the surrounding offices, clinic rooms and gait room (not separated with insulated walls) who continue to be exposed to these high levels of noise. The findings from these assessments support the need for a systematic approach to the identification of hazards and risk which will consider all aspects of the working environment.

One successful strategy implemented to address noise emissions from the grinders, (currently >85dB(A)), was to reduce the number of extraction outlets open and the fan speed to 60–70%. This strategy was not expected to reduce the efficiency of the extraction; however, further testing for efficacy is required. Changing the extraction method in the lamination room from the 2011 fixed ducts to the 2013 mobile ducts was successful in reducing the noise levels in this room. Chiselling out of casts, a daily task, results in high levels of noise emission. A suitable engineering control, confining or isolating the task to a "noise room" to prevent exposure to those not performing these activities, would be an alternative way of managing this hazard.

Limitations within the data include the number of people present at the two testing occasions. In 2013, a number of staff were away due to illness. As a result of the lower staff numbers ambient noise and VOC levels may be reduced, as the number of machines used and number activities being undertaken are likely to be fewer. The assessments which were conducted were focussed on ambient rather than individual exposures and biological monitoring and audiometric findings were not included. These factors could be addressed in future assessments.

Conclusion

Current occupational environmental exposures in Prosthetics and Orthotics are of concern to the P&O profession. A pilot study of one facility demonstrated that Occupational Noise exposures are high and may result in hearing loss and other adverse health outcomes. Occupational chemical exposures through volatile organic compound exposures in this setting are relatively low. Further, systematic investigation is required using a risk management framework of identification and assessment to develop evidence-based control strategies for all potentially hazardous workshop exposures, including relevant physical, biological and environmental hazards. Additional research across a number of facilities is required to collect evidence, which can be used to develop guidelines to improve the P&O work environment for P&Os, technician, patients and other staff.

Author Contributor Statement

Sarah Anderson completed the first draft and analysis of the data. All other authors contributed to the preparation of the manuscript.

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